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Characterization of U.S. Cement Kiln Dust

By Benjamin W. Haynes and Gary W. Kramer

UNITED STATES DEPARTMENT OF THE INTERIOR

(United States. Bureau of Mines)

Information Circular 8885

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UNITED STATES DEPARTMENT OF THE INTERIOR
James G. Watt, Secretary

BUREAU OF MINES
Robert C. Horton, Director

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ERRATA

Page 2, first 3 lines of right-hand column should read as follows:

EPA study of the cement industry concluded that:

Page 6, line 5 of right-hand column:

3.8 should be 7.7

Page 8, line 6 of right-hand column:

0.60 should be 0.68

Page 17, table 10:

Under Pb, delete -.44
Under Sr, delete -0.77

Page 18, line 4 of right-hand column:

Expression in parentheses should be (r = 0.77).

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CHARACTERIZATION OF U.S. CEMENT KILN DUST

By Benjamin W. Haynes[1] and Gary W. Kramer[2]

ABSTRACT

Cement kiln dust (CKD) produced in the contiguous United States and Hawaii was characterized as part of the Bureau of Mines' program in minerals environmental technology. The mineralogical and chemical composition was determined for 113 CKD samples from 102 plants that normally send CKD waste to landfill. Characterization included the determination of 28 elements, 7 anion species, carbon dioxide, noncarbonate carbon, and chemically bound water. Mercury was determined in 16 samples. Interelement correlation coefficients were determined for 23 elements, 5 anions, CO_2, noncarbonate carbon, and chemically bound water.

To assess the hazardous waste potential of CKD, the U.S. Environmental Protection Agency Extraction Procedure (EP) toxicity test was performed on all 113 CKD samples. All but one sample were in compliance with the test; the noncomplying sample slightly exceeded the EP toxicity test criterion for lead.

[1]Supervisory research chemist, Avondale Research Center, Bureau of Mines, Avondale, Md.

[2]Research chemist, Avondale Research Center, Bureau of Mines, Avondale, Md.

INTRODUCTION

Cement kiln dust (CKD) is a waste product that accumulates at the rate of 4 to 12 million tons per year in the United States (2, 4)[3]. This dust has considerable resource potential: It is already being used as a neutralizer for coal mine waste effluents, and the agricultural and construction industries are beginning to use it more extensively as a substitute for lime. In the proposed hazardous waste guidelines of 1978 (4) promulgated under the Resource Conservation and Recovery Act (RCRA) of 1976 (11), the Environmental Protection Agency (EPA) placed CKD in a "Special Wastes" category pending more information on the composition, characteristics, and degree of hazard posed by this waste. In 1980 the "Special Wastes" category was removed (5), but a 3-year EPA study of the hazard potential of CKD was approved by Congress (10). Part of the concern over the environmental effects of waste CKD resulted from a single study of the heavy metals content of a CKD sample from Blaubeuren, West Germany, showing lead and zinc contents of 5,620 and 16,200 μg/g, respectively (3). The only other analysis of CKD for heavy metals used in the EPA study was sample from Polk County, Ga., showing 124 μg/g for lead and 145 μg/g for zinc (12). A contracted EPA study of the received in 1-gallon cans and prepared cement industry concluded that:

> Waste kiln dust is probably the most serious pollution control problem facing the cement industry at this time. Relatively little is known about the dust, so environmentally adequate management techniques are difficult to specify (2).

An exploratory evaluation of the environmental effects and of the resource recovery potential of the elements present in CKD was initiated at the Bureau of Mines Avondale (Md.) Research Center shortly after publication of the 1978 EPA guidelines. Results of the first phase of this research (8), discussed major, minor, and trace element concentrations, mineralogy, anion composition, chemically bound water, CO_2, and EP toxicity leach test results. The present report gives characterization data for the U.S. cement industry nationwide. Information on noncarbonate carbon has been added for all samples, as have mercury determinations on selected samples, and significant interelement correlation coefficients for the major, minor, and trace elements.

SAMPLES

Samples of CKD were requested from operating plants located in the contiguous United States and Hawaii; 113 samples from 102 plants, representing about 70 percent of the total U.S. cement industry, were received and analyzed. The remaining plants either did not respond to the inquiry or had no disposal problems because all their waste dust was recycled. Table 1 lists the States and the number of samples received from each State. Samples were received in 1-gallon cans and prepared for analysis by the following procedure:

1. The sample as received was blended in a twin-shell blender for 30 minutes, then riffle-split into two portions.

2. One half of the sample was labeled and stored, and the other half was passed through a 100-mesh sieve. Any portion of the sample coarser than minus 100 mesh was ground in a Wiley mill[4] to pass 100 mesh.

[3]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

[4]Reference to specific brand names is made for identification only and does not imply endorsement by the Bureau of Mines.

TABLE 1. - Cement kiln dust samples received, by State[1]

State	Number of samples	State	Number of samples	State	Number of samples
Alabama.....	4	Kentucky.....	1	Ohio.....	5
Arizona.....	3	Louisiana.....	1	Oklahoma.....	3
Arkansas.....	2	Maine.....	0	Oregon.....	1
California...	11	Maryland.....	3	Pennsylvania...	9
Colorado.....	4	Michigan.....	3	South Carolina.	1
Florida.....	2	Mississippi....	1	South Dakota...	3
Georgia.....	1	Missouri.....	6	Tennessee.....	5
Hawaii.....	1	Montana.....	1	Texas.....	14
Idaho.....	1	Nebraska.....	3	Utah.....	1
Illinois.....	2	Nevada.....	0	Virginia.....	1
Indiana.....	2	New Mexico.....	1	Washington.....	4
Iowa.....	4	New York.....	2	Wisconsin.....	0
Kansas.....	5	North Carolina.	1	Wyoming.....	1

[1]Only those States are listed that have cement plants in operation.

3. The minus 100-mesh material (~ 1/2 gallon) was reblended for 30 minutes.

4. The sample was then riffle-split again into two fractions for characterization.

All mineralogical and chemical analysis data were obtained using the minus 100-mesh material. The extraction procedure (EP) toxicity leach test was performed on the blended as-received material. Samples were coded based on receipt date, and the tables of data have no correlation with the State listings in table 1.

MINERALOGY

Standard X-ray diffraction procedures using CuKα radiation were performed on the minus 100-mesh material to determine the minerals present. The results are given in table 2. All but seven samples contained calcite ($CaCO_3$) as a major constituent, and those seven samples had calcite as a minor constituent. All but two samples contained quartz (SiO_2). Lime (CaO) and anhydrite ($CaSO_4$) were present in most samples; amounts ranged from <5 to >30 wt-pct. Other minerals identified in the samples included aphthitalite [$(K,Na)_2SO_4$, nine samples], arcanite (K_2SO_4, nine samples), sylvite (KCl, nine samples), slaked lime [$Ca(OH)_2$, six samples], halite (NaCl, one sample), and gypsum ($CaSO_4 \cdot 2H_2O$, one sample). Two samples contained low levels of chlorite [$Mg_3(Si_4O_{10})(OH)_2 \cdot Mg_3(OH)_6$].

TABLE 2. - Mineralogical composition of U.S. cement kiln dust samples[1]

Sample	Calcite	Lime	Anhydrite	Quartz	Dolomite	Mica	Feldspar
1	Major	Minor	Minor	Minor	Minor		Minor
2	Major	Minor	Very low	Minor			
3	Major	Minor	Low	Low	Minor		Low
4	Major	Minor	Minor	Low	Low	Very low	
5	Major	Minor	Minor	Low	Very low	Very low	
6	Major	Major	Major	Very low			
7	Major	Major	Minor	Low			Low
8	Major	Minor	Low	Low	Low		Minor
9	Major		Low	Low	Low	Very low	Minor
10	Major	Minor	Minor	Very low	Low	Very low	
11	Major	Minor	Low	Minor			
12	Major		Low	Low	Minor	Very low	Minor
13	Major		Very low	Low	Minor	Low	Minor
14	Major		Minor	Low	Minor		
15	Major	Minor	Minor	Minor	Minor		
16	Major	Minor	Low	Low	Low		
17	Major		Low	Minor	Low		Low
18	Major	Minor	Minor	Minor			
19	Major	Minor	Minor	Minor	Minor		Very low
20	Major	Minor	Low	Very low			
21	Major	Minor	Minor	Low	Minor		
22	Major	Low	Minor	Low			
23	Major		Low	Very low	Low		
24	Major	Low	Low	Low	Low		
25	Minor	Major		Low			
26	Major	Minor	Minor	Very low			
27	Major	Minor	Low	Low			
28	Major	Low		Low			
29	Major	Minor		Low			
30	Major	Minor	Minor	Low	Low		
31	Major		Very low	Low			
32	Major	Minor	Low	Low			
33	Major	Low	Low	Very low			
34	Major	Minor	Low	Low			
35	Major	Minor	Minor	Low			
36	Major	Minor	Minor	Very low			
37	Major	Low	Minor	Very low	Low		
38	Major	Very low		Low	Low		
39	Major	Minor	Low	Low	Low		
40	Major	Minor		Very low	Low		
41	Major	Minor	Low	Very low			
42	Major	Major	Minor	Very low			
43	Major	Minor	Minor	Very low			
44	Major	Very low	Minor	Very low	Very low		
45	Major	Very low	Very low	Very low			
46	Minor			Very low		Very low	
47	Major	Low	Low	Very low	Low		
48	Major			Very low		Very low	

[1]See footnotes at end of table.

TABLE 2. - Mineralogical composition of U.S. cement kiln dust samples[1] —Continued

Sample	Calcite	Lime	Anhydrite	Quartz	Dolomite	Mica	Feldspar
49	Major		Low	Very low	Low		
50	Major			Very low			
51	Major	Very low	Low	Very low	Very low		
52	Major	Minor	Low	Very low			
53	Major	Low	Low	Low		Very low	
54	Major	Minor		Very low	Low	Very low	
55	Major	Major	Very low	Very low	Very low		
56	Major	Minor	Very low	Low	Low		Low
57	Major			Very low		Very low	
58	Major			Very low	Low		
59	Major	Low	Low	Very low			
60	Major	Low	Low	Very low	Low		
61	Major	Low	Low	Very low			
62	Major	Minor	Low	Very low	Low		
63	Major			Very low	Low		
64	Major	Major		Very low	Very low		
65	Major		Low	Very low	Minor		
66	Major	Low	Low	Very low	Low		
67	Major			Very low	Low		
68	Major			Very low			
69	Major	Low		Very low	Low		
70	Major	Low		Very low			
71	Major	Minor	Very low	Very low			
72	Major	Minor		Low			
73	Major	Low	Very low	Very low			
74	Major	Low	Low		Low		
75	Major	Minor	Low	Very low			
76	Major			Low	Low		
77	Major	Minor	Low	Low			
78	Major	Low	Very low	Low		Very low	
79	Major	Very low	Low	Low	Very low		
80	Major	Minor		Low		Very low	
81	Major	Very low		Very low			
82	Major	Minor		Very low			Low
83	Major	Minor	Low	Very low			
84	Major	Minor	Very low	Very low			
85	Major	Very low		Very low			Very low
86	Major	Minor	Low	Very low			
87	Major	Low	Low	Very low	Very low		
88	Major	Low		Very low			
89	Major	Low		Low			
90	Minor	Major	Minor	Very low			
91	Minor	Major	Low	Very low			
92	Major	Minor	Very low	Very low			Minor
93	Major	Low	Low	Very low			
94	Major	Low		Very low			

[1] See footnotes at end of table.

TABLE 2. - Mineralogical composition of U.S. cement kiln dust samples[1] --Continued

Sample	Calcite	Lime	Anhydrite	Quartz	Dolomite	Mica	Feldspar
95	Major	Minor	Minor				
96	Major	Low	Low	Low		Very low	
97	Major	Low	Low	Very low			
98	Major		Very low	Low		Very low	
99	Major	Low	Low	Very low			
100	Major	Very low		Very low			
101	Major	Minor	Very low	Very low		Very low	
102	Minor	Major	Low	Very low			
103	Major	Low	Low	Low			
104	Major	Minor		Low			
105	Major	Low		Very low			
106	Major	Minor	Very low	Very low			
107	Major		Very low	Very low			
108	Low	Major	Very low	Very low			
109	Major		Minor	Very low			
110	Major	Low	Low	Very low			
111	Major	Low	Low	Low	Low		
112	Major	Minor		Low			
113	Very low	Major		Very low			

Major	>30 wt-pct.	Very low	<5 wt-pct.
Minor	10-30 wt-pct.	Blank	Not detected.
Low	5-10 wt-pct.		

[1]Analysis by C. W. Huggins, research chemist, Avondale Research Center, Bureau of Mines, Avondale, Md.

CHEMICAL ANALYSES

The chemical analyses of the CKD samples are discussed in three sections as follows: (1) Chemically bound water, carbon dioxide and noncarbonate carbon concentrations; (2) anion concentrations; and (3) major, minor, and trace element concentrations. The samples used for the analyses were the blended minus 100-mesh materials.

Chemically Bound Water, Carbon Dioxide, and Noncarbonate Carbon

The amount of chemically bound water and carbon dioxide (CO_2) present in CKD was determined using thermogravimetric analysis (TGA). Chemically bound water and CO_2 are defined as the water and CO_2 requiring temperatures greater than 110° C to expel them from the material being analyzed. The results of the TGA analyses are shown in table 3. Chemically bound water was low in all samples, ranging from 0.4 to 3.8 wt-pct. The CO_2 content ranged from 4.4 to 34.4 wt-pct. No data are reported for chemically bound water and CO_2 for samples 17, 46, 57-59, 72, 82, and 84 because under the high-temperature, low-vacuum conditions of the analysis, vapors from the samples repeatedly corroded the 20-mil platinum-rhodium hangdown wire to the breaking point before the determination could be made. These samples contained high levels of sylvite (KCl), which attacks platinum-rhodium alloys.

TABLE 3. - Chemically bound water, CO_2, and noncarbonate carbon in U.S. cement kiln dust, wt-pct

Sample	Chemically bound water[1]	CO_2[1]	Noncarbonate carbon	Sample	Chemically bound water[1]	CO_2[1]	Noncarbonate carbon
1	0.7	22.3	0.41	46	ND	ND	1.83
2	.4	23.8	.51	47	1.2	22.9	.19
3	.8	19.4	1.01	48	1.0	22.9	.44
4	1.9	26.5	.62	49	.8	30.2	.21
5	1.3	24.2	.78	50	1.1	34.4	.32
6	.4	8.0	.50	51	2.9	16.5	.82
7	.4	8.8	.56	52	1.0	20.5	.10
8	.4	17.5	.50	53	1.0	21.0	.26
9	.8	21.9	.58	54	1.3	27.3	.61
10	1.3	22.6	1.00	55	1.5	19.2	.20
11	.9	19.1	.42	56	1.4	26.0	.48
12	1.1	19.6	.41	57	ND	ND	.54
13	1.3	23.7	.18	58	ND	ND	.53
14	1.1	21.7	.65	59	ND	ND	<.01
15	.8	12.4	.85	60	2.1	18.1	.78
16	1.0	23.9	.05	61	.9	22.0	.23
17	ND	ND	.75	62	1.5	26.4	1.40
18	1.3	19.6	.74	63	.8	34.2	1.22
19	.7	29.4	1.23	64	1.0	13.5	.56
20	1.2	26.2	.68	65	1.1	22.2	.41
21	.9	27.1	.70	66	2.0	19.0	1.00
22	2.0	20.6	.32	67	2.0	25.1	.41
23	.7	10.4	.54	68	3.8	23.0	.72
24	1.8	23.5	.23	69	1.4	22.2	1.02
25	1.4	14.3	.49	70	.6	25.1	1.63
26	1.8	16.8	.38	71	1.5	20.8	.54
27	.8	15.2	.77	72	ND	ND	.44
28	1.1	27.7	<.01	73	1.0	30.9	.51
29	.9	23.8	.44	74	1.1	25.9	1.10
30	1.0	31.3	.61	75	1.1	20.7	.42
31	2.9	24.3	.23	76	1.0	33.2	<.01
32	1.4	24.3	.52	77	1.3	13.0	.40
33	1.3	19.8	.46	78	1.2	30.1	.29
34	1.1	23.8	.66	79	2.5	21.8	.12
35	3.0	17.1	.39	80	1.5	23.3	.55
36	2.0	20.7	.30	81	1.5	12.6	.07
37	1.1	24.0	.49	82	ND	ND	<.01
38	1.1	32.6	.71	83	.7	26.0	.88
39	1.0	26.5	.77	84	ND	ND	.45
40	1.1	22.1	.78	85	1.6	28.3	.24
41	.9	25.9	1.60	86	1.0	17.9	.62
42	1.0	19.2	.97	87	1.6	22.4	.19
43	1.1	20.4	.98	88	.7	18.3	.03
44	1.2	25.2	.84	89	1.0	24.0	.14
45	2.1	20.0	.99	90	1.0	15.3	.20

[1]See footnotes at end of table.

TABLE 3. - Chemically bound water, CO_2, and noncarbonate carbon in U.S. cement kiln dust, wt-pct--Continued

Sample	Chemically bound water	CO_2	Noncarbonate carbon	Sample	Chemically bound water	CO_2	Noncarbonate carbon
91	1.8	12.0	0.15	103	2.8	22.4	0.18
92	1.2	27.0	.17	104	1.3	25.1	.86
93	1.8	19.1	.25	105	1.2	26.6	.23
94	.9	15.4	.15	106	1.4	23.0	.21
95	1.3	20.6	.06	107	1.0	31.7	.56
96	1.3	24.0	.23	108	2.4	4.4	.34
97	1.7	23.8	.11	109	3.0	21.9	.70
98	1.9	23.8	.13	110	1.4	20.5	1.23
99	1.1	33.3	.44	111	.5	31.5	.44
100	1.3	23.3	.11	112	.9	23.7	.33
101	1.0	21.8	.24	113	.8	8.2	.45
102	7.7	8.7	.64				

ND Not determined.

[1]Analysis by J. V. Scalera, chemist, Avondale Research Center, Bureau of Mines, Avondale, Md.

Noncarbonate carbon was determined by treating a weighed sample with dilute HCl and heating to dissolve the carbonate minerals present (calcite, dolomite.) After evolution of CO_2 ceased, the samples were rinsed to remove excess acid and analyzed by a LECO carbon analyzer. Noncarbonate carbon is generally unburned coal or fuel oil in the CKD samples. The concentrations as shown in table 3 ranged from <0.01 to 1.83 wt-pct.

Anions

The anion species present in the CKD samples were determined using a Dionex 10 ion chromatograph. The CKD samples were weighed and then fused with Na_2CO_3. After fusion, the samples were leached with high purity deionized distilled water and diluted to a standard concentration; and aliquots of a 1-to-10 dilution were injected into the ion chromatograph.

Details of this procedure are given elsewhere (7). Determinations of chloride (Cl^-), fluoride (F^-), nitrate (NO_3^-), phosphate (PO_4^{3-}), and sulfate (SO_4^{2-}) were obtained from a single sample injection. The results of these determinations on the U. S. CKD samples are presented in table 4. Chloride ranged from <0.01 to 12.3 wt-pct, fluoride from 0.01 to 0.60 wt-pct, nitrate from <0.02 to 1.67 wt-pct, phosphate from <0.02 to 0.16 wt-pct, and sulfate from 0.41 to 31.6 wt-pct. Bromide (Br^-) and nitrite (NO_2^-) can also be determined by this method from the same injection of solution, but no samples were found to contain either Br^- or NO_2^- at levels greater than the detection limit (<0.02 wt-pct) for these anions.

Major, Minor, and Trace Elements

The elements Al, Si, K, Ca, Ti, and Fe were determined for the majority of samples by a fused-disk fluorescent X-ray spectrography procedure. Fifteen CKD samples were analyzed for the above elements by wet chemical techniques, and these samples were used as secondary standards for the X-ray method. Other major, minor, and trace elements were determined by flame atomic absorption spectroscopy (AAS). Samples were

TABLE 4. - Anions in U.S. cement kiln dust, wt-pct

Sample	Cl^-	F^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	Sample	Cl^-	F^-	NO_3^-	PO_4^{3-}	SO_4^{2-}
1	0.01	0.13	0.76	<0.02	9.77	58	1.03	0.06	<0.02	<0.02	2.02
2	.04	.08	.05	.05	2.63	59	1.09	.09	<.02	<.02	10.8
3	.90	.09	.32	<.02	9.06	60	.35	.16	<.02	<.02	10.6
4	.18	.13	.11	.05	7.43	61	.89	.12	<.02	.02	8.21
5	.10	.14	.23	.05	7.93	62	.19	.04	.12	<.02	6.63
6	.04	.36	.32	.08	12.2	63	.16	.06	<.02	<.02	1.15
7	.66	.31	.23	.02	12.4	64	.24	.26	.07	<.02	2.64
8	1.93	.10	.09	<.02	19.2	65	.29	.08	<.02	<.02	19.8
9	5.18	.07	1.00	<.02	12.0	66	.40	.12	<.02	<.02	10.8
10	.42	.26	.37	.05	7.95	67	.13	.14	<.02	.02	3.56
11	<.01	.05	<.02	<.02	4.15	68	.26	.20	<.02	<.02	5.38
12	.17	.22	.21	<.02	10.7	69	.06	.04	<.02	<.02	4.26
13	.52	.04	.23	.10	14.7	70	.13	.68	<.02	.02	6.29
14	.18	.10	.05	<.02	18.6	71	.52	.05	.07	<.02	2.60
15	<.01	.23	<.02	<.02	14.2	72	3.32	.15	<.02	<.02	3.73
16	.21	.12	.56	.10	4.96	73	.58	.08	<.02	<.02	2.22
17	.89	.09	.09	<.02	6.05	74	.59	.05	<.02	.02	6.59
18	1.17	.20	.23	.16	4.91	75	.63	.11	<.02	<.02	7.42
19	.57	.03	.19	<.02	12.4	76	.48	.10	<.02	.03	6.02
20	.19	.08	1.67	.03	10.4	77	.49	.25	<.02	<.02	10.7
21	.56	.11	.10	<.02	7.27	78	.38	.05	<.02	<.02	.82
22	.38	.12	.12	<.02	10.5	79	.62	.07	<.02	<.02	7.52
23	.40	.35	<.02	<.02	31.6	80	.35	.07	<.02	.03	2.29
24	.12	.16	<.02	<.02	3.77	81	1.20	.20	.11	.02	21.5
25	.04	.13	<.02	<.02	1.66	82	.70	.19	<.02	<.02	12.5
26	.15	.09	<.02	<.02	10.9	83	.51	.10	<.02	<.02	7.59
27	1.01	.05	<.02	<.02	6.63	84	1.36	.19	<.02	<.02	3.48
28	.28	.11	<.02	<.02	9.52	85	.49	.15	<.02	<.02	.41
29	.35	.11	.74	<.02	6.16	86	.55	.16	<.02	<.02	11.6
30	.15	.15	<.02	<.02	6.27	87	.51	.14	<.02	<.02	5.12
31	1.13	.14	<.02	<.02	5.85	88	.52	.22	.09	.02	6.51
32	.45	.04	<.02	<.02	.86	89	.38	.12	<.02	<.02	3.83
33	1.97	.01	<.02	<.02	1.83	90	.57	.16	<.02	<.02	12.3
34	.47	.10	.15	<.02	5.31	91	.86	.20	<.02	<.02	6.61
35	.41	.05	.41	<.02	5.72	92	.38	.04	<.02	<.02	3.80
36	.49	.10	<.02	<.02	8.01	93	.42	.16	<.02	.02	7.68
37	.51	.07	.15	<.02	7.20	94	.39	.19	<.02	<.02	6.16
38	.82	.09	<.02	<.02	.61	95	.42	.07	<.02	<.02	10.2
39	.31	.06	.23	<.02	2.35	96	.49	.10	<.02	<.02	5.42
40	.78	.18	.18	<.02	5.46	97	.25	.13	<.02	<.02	6.12
41	.52	.12	<.02	<.02	4.85	98	.80	.06	<.02	<.02	7.15
42	.13	.14	<.02	<.02	8.37	99	.42	.05	<.02	<.02	3.70
43	.58	.13	<.02	.02	15.7	100	.46	.29	.07	<.02	9.16
44	.44	.07	<.02	<.02	10.8	101	.47	.20	<.02	<.02	3.38
45	.11	.09	<.02	<.02	5.68	102	.16	.09	<.02	<.02	5.31
46	12.3	.05	<.02	<.02	31.5	103	.87	.09	<.02	<.02	5.92
47	.84	.12	<.02	<.02	9.05	104	.43	.11	<.02	<.02	2.13
48	.82	.04	.07	<.02	1.01	105	1.00	.09	<.02	<.02	3.42
49	.73	.05	.07	.02	2.86	106	1.32	.13	<.02	<.02	4.84
50	.48	.07	<.02	.04	.49	107	.35	.07	<.02	<.02	2.21
51	.39	.20	<.02	<.02	15.3	108	1.84	.16	<.02	<.02	14.0
52	.52	.05	<.02	<.02	6.43	109	.71	.05	.16	<.02	13.9
53	.36	.07	<.02	<.02	7.15	110	.47	.16	<.02	.02	11.8
54	.31	.09	<.02	<.02	4.04	111	.21	.14	<.02	<.02	2.92
55	.34	.12	<.02	<.02	6.86	112	.22	.31	<.02	<.02	2.30
56	.39	.10	<.02	<.02	1.70	113	2.56	.40	<.02	<.02	5.22
57	.72	.33	<.02	<.02	22.0						

prepared for AAS analysis by dissolving 2 grams of CKD sample in a mixture of 10 ml concentrated HNO_3, 5 ml HF, and 40 ml distilled H_2O. The sample was evaporated to dryness. The dried sample was redissolved in 5 vol-pct HNO_3 to which 5 ml of 30-pct H_2O_2 was added. The solution was gently heated and, after the H_2O_2 reaction had subsided, 5 to 10 ml of concentrated HCl was added to dissolve the remaining solids. The samples were cooled and transferred to volumetric flasks for AAS analysis.

Arsenic and antimony were determined by a reliable graphite furnace AAS method developed by the Bureau of Mines (6, 9). Mercury was determined using the method of Agemian and Chau (1) as modified by Haynes (9).

Duplicate analyses were performed on all CKD samples. To verify the results obtained by chemical dissolutions, the flame AAS procedure, and other procedures used in this report, a National Bureau of Standards (NBS) Standard Reference Material (SRM) cement standard, SRM-637, was analyzed, and these values were compared with certificate results. The results are listed in table 5 and show good agreement between certified values and values obtained by the methods used in this study.

The results for the major and minor element concentration [arbitrarily chosen as greater than 0.05 wt-pct (500 µg/g)] are given in table 6. Table 7 gives the trace element concentration [arbitrarily selected as less than 0.05 wt-pct (500 µg/g)].

Also listed in table 7 are seven elements, and their detection limits, that were not detected by flame atomic absorption in any of the samples. Twenty-eight elements were examined in all of the samples. Thallium was detected in only one sample, at 185 µg/g. The presence of thallium in sample 9, as determined by flame AAS, was verified by fluorescent X-ray spectrography and optical emission spectroscopic techniques.

TABLE 5. - Comparison of NBS SRM-637 certificate values with Bureau of Mines analytical method values, wt-pct

Constituent	Concentration	Certified value[1]
CaO.....	65.8	66.0(4)
SiO_2.....	23.2	23.0(7)
Al_2O_3....	3.15	3.2(8)
Fe_2O_3....	1.72	1.80
SO_3.....	2.28	2.3(8)
MgO.....	.62	.6(7)
K_2O.....	.22	.25
TiO_2.....	.21	.21
Na_2O.....	.13	.15
SrO.....	.08	.09
P_2O_5.....	.22	.24
Mn_2O_3....	.06	.06
F.....	.04	.04
ZnO.....	.01	.01
Cr_2O_3....	.01	.01

[1]Parentheses indicate estimated level by NBS of next digit.

Table 8 lists the range, arithmetic mean, and median found for each element in the 113 CKD samples. Ranges over three orders of magnitude are seen for some elements. The median may indicate the most probable value for the CKD samples where an anomalously high or low value for an element was found in one of the samples. Except for Ca, Ni, and Si, the median is lower than the mean for each element, indicating that the high concentrations are less frequent than the lower concentrations.

Because traces of mercury were leached from only a few samples by the EP toxicity test, these samples and a few additional samples were chosen to insure an adequate geographic representation of the plants in the United States. Table 9 gives the results of analysis of 16 samples chosen by the above procedure. Mercury was determined by standard cold vapor AAS procedures (1, 9).

TABLE 6. - Major and minor elements in U.S. cement kiln dust, wt-pct

Sample	Al	Ca	Fe	K	Mg	Na	Si	Sr	Ti
1	1.74	31.6	1.41	1.96	1.76	0.73	6.68	0.02	0.12
2	2.05	36.1	1.58	.68	.87	.50	5.29	.02	.16
3	2.66	31.8	1.51	5.04	.37	.47	6.33	.04	.14
4	2.89	29.4	1.38	2.50	1.39	.45	6.63	.08	.13
5	2.71	32.8	1.17	1.50	1.16	.42	5.72	.08	.12
6	3.82	32.0	3.61	3.73	.96	.45	7.62	.17	.20
7	3.40	27.3	2.58	3.65	1.21	.54	7.16	.18	.16
8	1.69	22.2	1.10	11.9	.68	.59	4.14	.02	.09
9	2.37	19.8	1.03	8.78	1.01	.96	4.93	.04	.10
10	3.99	24.0	2.24	4.16	1.12	.57	6.24	.08	.20
11	2.61	34.1	2.53	1.10	.70	.19	8.64	.04	.13
12	2.58	29.2	1.48	3.53	1.91	1.18	6.93	.08	.12
13	2.44	23.6	1.39	5.99	1.59	.91	4.13	.08	.13
14	1.71	23.9	.89	6.89	1.26	1.15	4.35	.17	.09
15	2.53	30.3	1.81	5.95	1.10	.58	7.09	.07	.12
16	2.21	33.7	1.35	2.43	1.01	.62	6.93	.04	.14
17	2.50	30.5	1.31	3.53	.63	.48	5.90	.03	.11
18	5.02	21.3	2.39	2.01	.31	1.44	11.1	.50	.29
19	2.07	31.5	1.62	2.68	.35	.98	6.00	.07	.14
20	2.34	33.5	1.41	2.21	.48	.50	5.31	.04	.13
21	1.97	30.5	1.83	1.66	1.46	.30	7.79	.05	.11
22	2.50	28.5	1.50	2.42	.81	.44	8.16	.03	.13
23	1.44	11.3	2.29	15.1	.34	2.36	3.30	.02	.07
24	3.22	26.7	1.94	2.79	1.56	.20	8.94	.04	.16
25	2.10	34.5	1.64	2.11	1.10	.25	7.33	.06	.11
26	2.58	31.6	2.37	1.43	.66	.21	6.83	.04	.10
27	2.05	31.6	1.18	2.43	1.02	.16	7.65	.01	.10
28	1.92	28.7	1.11	4.34	.56	.48	4.90	.02	.09
29	1.80	33.0	1.35	1.77	.64	.23	7.40	.02	.08
30	1.86	33.2	1.03	1.86	1.35	.09	5.53	.01	.11
31	1.95	30.7	1.22	2.19	.34	.89	8.02	.22	.11
32	2.54	33.2	1.72	.72	.29	.15	8.71	.01	.13
33	2.99	32.7	1.50	2.56	.31	.20	5.63	.12	.16
34	2.62	31.8	1.81	2.47	.30	.18	7.56	.05	.10
35	2.45	33.8	1.77	.61	.35	.18	7.53	.11	.10
36	2.01	32.0	1.68	2.35	.46	.30	6.51	.07	.09
37	2.64	28.4	1.60	3.05	1.17	.30	8.20	.04	.13
38	1.84	31.6	.98	1.84	1.66	.05	6.55	.03	.08
39	2.04	33.4	.91	1.69	1.38	.22	6.72	.02	.10
40	2.63	30.9	1.43	2.55	.79	.07	7.13	.05	.13
41	2.11	34.6	1.42	.86	.69	.32	6.16	.10	.10
42	2.11	34.6	1.42	.86	1.48	.18	6.16	.05	.10
43	2.52	27.3	1.33	5.51	.31	.48	5.63	.08	.12
44	2.03	28.3	1.30	3.72	.84	.38	6.17	.02	.12
45	2.32	27.2	1.56	5.04	.64	.77	6.72	.12	.12
46	.99	10.6	.66	23.2	.24	.71	3.60	.01	.06

TABLE 6. - Major and minor elements in U.S. cement kiln dust, wt-pct --Continued

Sample	Al	Ca	Fe	K	Mg	Na	Si	Sr	Ti
47	2.50	28.4	1.65	3.53	1.20	0.40	7.07	0.02	0.16
48	2.23	33.2	1.27	1.02	.66	.14	5.72	.03	.13
49	1.90	33.1	1.36	1.11	1.24	.12	6.51	.02	.16
50	2.26	36.0	1.00	.67	.34	.10	5.20	.05	.11
51	2.12	27.3	1.10	5.16	.30	.43	4.97	.08	.10
52	1.97	31.7	1.60	3.05	.41	.25	6.51	.02	.07
53	2.40	30.3	1.49	2.82	.82	.33	6.89	.06	.14
54	2.62	31.2	1.16	3.58	.76	.22	4.95	.05	.12
55	2.26	34.4	1.01	3.36	.77	.15	3.65	.05	.09
56	2.10	30.5	1.27	1.12	.98	.30	5.31	.04	.10
57	2.07	13.3	1.03	19.8	.57	.51	3.17	.03	.09
58	2.36	28.4	1.32	3.42	.78	.20	5.78	.05	.12
59	1.87	27.8	1.07	3.69	.70	.34	5.98	.08	.09
60	2.14	26.4	1.26	5.22	1.07	.76	6.19	.04	.12
61	2.16	27.2	2.03	5.19	.49	.35	6.20	.02	.11
62	2.14	34.5	1.16	1.87	.80	.49	5.08	.01	.11
63	2.35	33.8	1.01	1.28	.65	.09	5.66	.02	.12
64	2.72	34.1	1.41	3.80	.54	.45	5.83	.07	.12
65	1.72	21.5	.75	11.0	.65	.76	2.72	.03	.09
66	2.60	28.7	2.50	3.98	.53	.42	5.90	.03	.11
67	2.78	28.0	1.41	3.77	1.42	.68	7.28	.04	.14
68	1.92	27.0	.90	6.47	1.33	.88	5.69	.04	.11
69	1.98	31.6	1.52	2.25	1.06	.58	7.31	.02	.09
70	1.37	25.7	.79	11.6	.52	2.32	2.69	.02	.06
71	1.67	35.8	2.32	.34	.26	.15	7.00	.03	.07
72	2.30	27.3	1.93	4.46	.43	2.77	7.25	.88	.11
73	2.19	33.4	1.26	1.64	.91	.27	5.39	.07	.09
74	2.31	31.4	1.28	1.80	.52	.30	7.25	.01	.12
75	2.33	25.8	1.51	2.58	.81	.20	5.54	.07	.13
76	1.92	33.0	.98	.97	.80	.22	6.49	.07	.09
77	1.82	29.1	2.00	3.09	.84	.47	7.68	.04	.08
78	2.43	33.4	1.18	.65	.56	.22	7.09	.02	.12
79	2.72	29.4	1.77	2.19	.81	.42	7.43	.22	.14
80	1.72	34.9	1.59	1.07	.63	.28	7.12	.01	.10
81	2.63	19.4	1.59	10.1	.34	1.11	5.70	.07	.13
82	2.12	27.1	.10	5.52	.65	1.09	6.27	.02	.05
83	1.83	31.5	1.65	2.53	.60	.37	5.80	.06	.08
84	1.85	33.1	1.04	2.16	.49	.38	6.37	.08	.10
85	2.51	29.2	1.51	5.29	.20	.58	6.36	.06	.12
86	2.40	29.2	.94	5.56	.22	.27	6.97	.03	.11
87	2.46	32.0	1.52	2.48	.62	.21	6.88	.02	.12
88	2.28	26.5	1.16	6.38	1.05	.99	7.40	.02	.11
89	2.49	31.5	1.77	2.17	.59	.20	7.35	.08	.13
90	2.98	28.7	2.27	3.92	.67	.29	7.79	.03	.15
91	2.58	31.8	1.38	3.27	1.52	.26	6.26	.02	.12
92	1.93	35.1	1.26	.96	.27	.36	5.71	.06	.09
93	2.54	30.5	2.02	2.65	.43	.23	6.86	.17	.11

TABLE 6. - Major and minor elements in U.S. cement kiln dust, wt-pct --Continued

Sample	Al	Ca	Fe	K	Mg	Na	Si	Sr	Ti
94	2.64	30.4	1.27	3.27	0.45	0.26	7.15	0.17	0.11
95	1.90	31.6	1.12	1.14	.80	.29	6.56	.03	.09
96	1.72	27.7	1.15	4.44	.20	.73	6.72	.04	.09
97	2.66	27.7	1.74	2.80	.32	.34	7.34	.05	.13
98	1.86	28.1	1.46	2.70	.23	1.22	6.52	.12	.11
99	2.51	34.1	1.17	1.39	.34	.18	4.57	.04	.12
100	2.39	27.1	.93	5.97	.33	.83	5.77	.11	.10
101	2.96	29.8	1.43	2.74	.95	.18	8.54	.06	.17
102	2.45	34.3	1.48	1.98	.69	.19	6.55	.03	.12
103	2.05	32.2	1.81	1.73	.56	.72	5.67	.12	.23
104	1.87	29.3	1.68	2.08	.50	.14	7.26	.03	.10
105	2.05	31.1	.96	2.73	1.81	.20	5.46	.03	.09
106	2.18	30.1	1.06	3.37	1.70	.29	5.88	.03	.11
107	2.67	31.7	1.13	1.55	.36	.19	6.59	.08	.11
108	2.83	29.8	1.41	4.74	1.61	.24	6.53	.02	.14
109	2.92	26.1	4.44	1.93	1.38	.19	5.40	.04	.18
110	2.28	28.2	.95	5.09	.43	.32	6.36	.05	.11
111	2.43	33.4	1.35	2.03	.68	.21	7.33	.03	.12
112	2.61	35.2	1.74	1.96	.47	.10	7.70	.09	.13
113	2.53	36.7	.88	4.23	.54	.13	5.91	.08	.11

TABLE 7. - Trace elements in U.S. cement kiln dust, µg/g[1]

Sample	Ag	As	Cd	Cr	Cu	Li	Mn	Ni	Pb	Sb	Zn
1	<3	14	<1.5	30	18	17	205	<12	<26	<1.6	111
2	<3	7.2	<1.5	42	44	18	305	45	<26	<1.6	48
3	<3	23	6.8	27	23	19	588	18	159	<1.6	200
4	<3	5.9	<1.5	34	63	26	268	20	<26	<1.6	214
5	<3	4.3	<1.5	29	19	25	414	23	43	<1.6	50
6	<3	74	<1.5	69	28	14	278	45	44	3.0	118
7	<3	60	<1.5	59	24	14	341	<12	30	1.9	136
8	<3	15	29	29	18	26	166	<12	569	<1.6	455
9	<3	1.6	12	32	28	76	180	72	1,010	<1.6	127
10	<3	28	<1.5	51	26	58	334	32	366	<1.6	171
11	<3	13	<1.5	59	27	24	864	25	35	<1.6	112
12	17	5.7	<1.5	62	23	56	166	20	91	1.9	110
13	<3	1.5	5.8	34	29	37	1,330	<12	282	<1.6	180
14	12	8.0	<1.5	51	28	71	111	<12	187	<1.6	88
15	<3	20	1.6	99	22	19	250	37	106	<1.6	140
16	<3	7.3	5.8	41	18	33	202	24	<26	<1.6	216
17	<3	15	58	64	30	34	101	20	578	<1.6	229
18	<3	9.8	4.3	101	199	28	113	54	560	<1.6	1,330
19	<3	26	9	34	14	37	114	<12	900	<1.6	260
20	<3	14	11	116	17	16	63	31	84	1.6	76

[1]See footnote at end of table.

TABLE 7. - Trace elements in U.S. cement kiln dust, µg/g[1]--Continued

Sample	Ag	As	Cd	Cr	Cu	Li	Mn	Ni	Pb	Sb	Zn
21	11	5.1	8.6	29	27	<4	440	26	154	<1.6	299
22	11	6.3	22	48	30	23	489	33	204	1.6	500
23	11	34	22	172	34	62	139	18	454	1.9	774
24	14	11	6.4	47	57	18	204	34	278	3.4	475
25	11	9.3	6.2	35	18	<4	668	24	101	<1.6	67
26	6.7	8.4	6.4	64	18	<4	835	44	132	<1.6	156
27	6.7	11	7.7	43	18	<4	620	36	92	<1.6	162
28	7.0	14	5	18	56	<4	284	22	760	<1.6	1,860
29	6.5	12	4.5	24	94	<4	390	17	322	<1.6	1,330
30	6.5	8.7	5.8	22	18	<4	164	25	246	<1.6	38
31	7.2	19	3.2	34	24	<4	372	22	90	2.7	54
32	5.0	15	3.5	28	17	<4	150	26	76	2.3	53
33	6.0	7.6	5	58	24	24	222	29	73	<1.6	83
34	8.8	31	30	57	40	13	238	59	308	3.9	1,100
35	6.4	32	19	36	40	<4	632	47	56	3.3	180
36	5.9	20	8.2	36	24	14	535	32	128	5.8	228
37	5.0	6.9	5	30	26	18	224	26	128	3.9	295
38	6.6	6.6	5.4	49	23	18	488	16	112	<1.6	126
39	6.6	4.3	8.9	24	16	<4	174	14	86	<1.6	32
40	6.7	7.6	6	120	20	7.5	390	14	595	3.1	372
41	12	18	8.9	32	42	14	439	34	161	<1.6	167
42	11	6	6.9	42	28	12	128	37	66	1.7	145
43	10	18	8.2	31	27	23	1,370	52	231	2.5	516
44	7.5	7.1	7.3	21	24	11	2,410	41	223	<1.6	155
45	8.4	16	7.6	42	21	12	485	28	166	2.2	952
46	6.9	3.4	11	28	44	42	125	20	446	<1.6	628
47	6.4	8.6	7.8	53	34	11	376	30	494	<1.6	290
48	8.8	3.7	3.8	27	22	8.2	244	22	35	<1.6	105
49	8.6	4.6	8.8	90	54	<4	266	91	368	6.7	391
50	6.6	3	4.9	21	12	12	398	20	111	<1.6	55
51	9.8	17	8.6	64	30	14	462	33	216	3.9	354
52	3	28	70	34	56	<4	559	20	336	2.4	243
53	7.3	29	6	30	26	<4	343	26	101	2.7	220
54	9.7	8.8	6.4	40	52	<4	236	28	148	3.8	8,660
55	9.7	4.3	9.4	32	39	6.5	240	23	232	3.7	2,740
56	4.2	7.1	8.2	38	22	5	250	28	86	2.6	99
57	14	6.5	20	77	22	21	176	18	1,590	3	468
58	7.4	11	7	34	23	16	156	32	148	4.4	144
59	14	4	62	31	28	22	408	28	964	<1.6	158
60	11	2.3	18	33	26	18	173	28	202	<1.6	401
61	4.8	12	19	62	30	16	154	<12	132	<1.6	243
62	6.9	9.5	<1.5	36	27	16	252	12	76	<1.6	58
63	6.4	4.9	4	29	16	12	279	<12	36	<1.6	88
64	<3	7.1	4	56	20	20	457	<12	420	<1.6	167
65	<3	3.4	45	28	16	22	90	<12	288	<1.6	254
66	<3	33	2.8	39	32	18	677	16	160	<1.6	167
67	<3	5.2	14	64	28	16	304	12	126	<1.6	113
68	5.3	3.4	13	67	18	20	280	<12	94	<1.6	75

[1]See footnote at end of table.

TABLE 7. - Trace elements in U.S. cement kiln dust, µg/g[1]--Continued

Sample	Ag	As	Cd	Cr	Cu	Li	Mn	Ni	Pb	Sb	Zn
69	4.7	13	<1.5	35	21	6	240	<12	54	<1.6	71
70	7	44	6.8	56	18	18	67	<12	221	<1.6	199
71	5.4	18	2.6	27	24	8	188	<12	169	<1.6	146
72	5.5	5.8	<1.5	43	22	16	141	<12	68	<1.6	67
73	15	24	10	38	28	19	290	<12	150	11	154
74	7.4	10	2.6	37	54	32	239	17	98	<1.6	206
75	12	509	42	48	56	14	534	24	260	29	702
76	12	518	42	47	64	14	542	24	258	27	714
77	6.3	27	10	71	46	12	168	86	73	<1.6	158
78	8.8	29	8	43	23	10	357	<12	134	<1.6	125
79	5.5	12	9.5	33	18	17	424	<12	138	<1.6	778
80	7.9	25	5	47	34	8	236	14	31	<1.6	129
81	<3	23	7.8	43	46	47	1,090	<12	272	<1.6	703
82	<3	16	35	11	12	4.2	136	<12	1,240	<1.6	115
83	13	77	16	28	206	9.2	638	<12	1,750	42	7,860
84	<3	11	10	21	16	19	650	<12	204	<1.6	134
85	<3	19	12	47	18	20	580	<12	162	<1.6	200
86	<3	15	2	33	14	26	456	<12	81	<1.6	243
87	<3	20	3.1	23	9.4	11	592	<12	130	<1.6	258
88	<3	81	2.7	22	63	28	235	<12	568	18	1,650
89	<3	8	3.4	26	15	22	234	<12	<26	2	53
90	<3	54	3.4	23	36	21	350	<12	126	<1.6	580
91	<3	15	<1.5	37	10	14	300	<12	39	<1.6	32
92	<3	29	<1.5	24	34	15.6	274	<12	221	19	207
93	<3	10	12	30	25	17	1,060	<12	740	<1.6	1,220
94	<3	12	4.6	45	21	17	1,250	<12	376	<1.6	1,060
95	<3	80	8.8	16	29	7.6	265	<12	426	70	792
96	<3	13	26	49	12	6.6	370	<12	998	<1.6	120
97	<3	7.6	<1.5	80	21	21	286	<12	88	<1.6	83
98	<3	1.7	1.7	27	7	18	644	<12	142	<1.6	114
99	<3	2.2	<1.5	15	10	8.8	335	<12	34	<1.6	37
100	<3	2.1	5	33	11	45	259	<12	56	1.9	445
101	<3	3.9	64	34	28	46	300	<12	144	<1.6	516
102	<3	4.7	16	18	7.6	11	592	<12	80	2.7	88
103	<3	1.3	34	39	32	9.4	226	<12	62	2	104
104	<3	4.2	16	35	8.3	7.4	302	<12	66	2.7	83
105	<3	2.9	352	26	14	8.4	280	<12	182	<1.6	88
106	<3	2.8	305	23	18	9.4	266	<12	206	<1.6	108
107	<3	2.3	100	18	14	10	820	<12	362	<1.6	398
108	<3	11	24	35	24	16	410	<12	150	<1.6	150
109	<3	4.6	18	30	34	19	336	<12	542	1.8	207
110	<3	3.1	81	18	12	55	177	<12	182	1.9	322
111	<3	1.9	9.9	14	12	6.9	198	<12	38	<1.6	58
112	<3	1.7	66	15	13	8.2	203	<12	28	2.9	38
113	<3	3	141	18	16	10	248	<12	72	1.8	79

[1]Elements not detected in any of the samples:
Ba <55; Be <2; Bi <50; Co <10; Mo <50; Sn <100; V <100.

TABLE 8. - Elemental and anion variation in U.S. cement kiln dust, µg/g

Element or anion	Range	Mean[1]	Median
Ag	<3 - 17	5.4	4.8
Al	9,900 - 50,200	23,200	23,100
As	1.3 - 518	24	9.3
Ba	<55	<55	<55
Be	<2	<2	<2
Bi	<50	<50	<50
Ca	106,000 - 367,000	295,000	305,000
Cd	<1.5 - 352	21	7.3
Co	<10	<10	<10
Cr	11 - 172	41	34
Cu	7 - 206	30	24
Fe	1,000 - 44,400	14,700	14,100
Hg[2]	<0.13 - 1.0	<.13	<.13
K	3,400 - 232,000	36,600	26,800
Li	<4 - 76	18	16
Mg	1,980 - 19,100	7,820	6,820
Mn	63 - 2,410	383	280
Mo	<50	<50	<50
Na	495 - 27,700	4,700	3,190
Ni	<12 - 91	22	29
Pb	17 - 1,750	253	148
Sb	<1.6 - 70	3.2	<1.6
Si	26,900 - 111,000	63,500	65,100
Sn	<100	<100	<100
Sr	62 - 8,750	670	430
Ti	500 - 2,900	3,530	1,100
Tl	<60 - 185	<60	<60
V	<100	<100	<100
Zn	32 - 8,660	462	167
Br^-	<200	<200	<200
Cl^-	<100 - 123,000	6,900	4,900
F^-	100 - 3,600	1,300	1,000
NO_2^-	<200	<200	<200
NO_3^-	200 - 16,700	<200	<200
PO_4^{3-}	200 - 1,600	<200	<200
SO_4^{2-}	4,100 - 316,000	77,800	68,600

[1]A value of 1/2 the detection limit was arbitrarily used to calculate the mean for those elements having concentrations both above and below the detection limit.

[2]Mercury value based on only 16 samples.

TABLE 9. - Mercury in selected U.S. cement kiln dust samples, µg/g

Sample	Mercury	Sample	Mercury
8.....	<0.13	52....	0.25
9.....	1.0	58....	.13
13.....	.13	64....	<.13
14.....	<.13	65....	.38
17.....	<.13	68....	<.13
19.....	<.13	104....	1.0
35.....	.63	108....	<.13
49.....	<.13	110....	.63

Interelement Correlations

Interelement correlation coefficients were generated using linear regression analysis on a total of 23 elements, anions, carbonate carbon as CO_2, noncarbonate carbon, and chemically bound water. Coefficients with values r $\geq$0.4 or r $\leq$-0.4 were taken as significant positive or negative correlations. Of the 23 parameters tested, only 14 parameters showed significant correlation. Table 10 shows the interelement correlation coefficients for the 23 pairs. Some very significant correlations

TABLE 10. - Interelement correlation coefficients for U.S. cement kiln dust[1]

Element or anion	Al	Ca	Cl^-	CO	F^-	Fe	K
Al.....	1					0.46	
Ca.....		1	-0.45				-0.85
Cl^-.....		-.45	1				.56
CO				1	-0.42		
F^-.....				-.42	1		
Fe.....	.46					1	
K.....		-.85	.56				1
Li.....		-.54					.44
Na.....		-.55			.42		.47
Pb.....		-.42					
Si.....	.48						-.55
Sr.....							
SO_4^{2-}.....		-.77		-.51			.77
Ti.....	.77					.49	

Element or anion	Li	Na	Pb	Si	Sr	SO_4^{2-}	Ti
Al.....				0.48			0.77
Ca.....	-0.54	-0.55	-0.42		-0.77	-0.77	
Cl^-.....							
CO						-.51	
F^-.....		.42					
Fe.....							.49
K.....	.44	.47		-.55		.77	
Li.....	1	.41				.49	
Na.....	.41	1			0.52		
Pb.....			1				
Si.....				1		-.44	.42
Sr.....		.52			1		
SO_4^{2-}.....	.49		-.44	-.44		1	
Ti.....				.42			1

[1]Blank indicates that correlation coef ficient is insignificant (-0.4 < r <0.4).

($r>0.7$, $r<-0.7$) were found for Al and Ti ($r = 0.77$), Ca and K ($r = -0.85$), Ca and SO_4^{2-} ($r = -0.77$), and K and SO_4^{2-} ($r = -0.77$). Chlorine and potassium (the mineral sylvite, KCl) showed a positive correlation coefficient of $r = 0.56$. The remaining parameters of As, noncarbonate carbon, Cd, Cr, Cu, chemically bound water, Mg, Mn, and Zn had no significant correlations with any of the other parameters.

EPA HAZARDOUS WASTE TEST

According to EPA regulations, a solid waste must be listed as hazardous if it exhibits ignitability, corrosivity, reactivity, or toxicity, using the extraction procedure outlined in the Federal Register (4-5). CKD does not meet the criteria for a hazardous waste under ignitability, corrosivity, or reactivity. Briefly, the EP toxicity test as applied to CKD in this study consisted of adding 100 grams of CKD to 1,600 ml of distilled water, gradually adding 400 ml of 0.5-normal acetic acid, and agitating for 24 hours. Although 400 ml of acetic acid was the maximum amount specified by the test procedure, the pH never approached the specified pH of 5 ±0.2. The resulting extract in the EP toxicity test must not exceed 100 times the National Drinking Water Standard with respect to the concentration of eight metals: As, Ba, Cd, Cr, Pb, Hg, Se, and Ag. Table 11 lists the allowed maximum concentrations. Only one sample exceeded any of the limits; this sample (83) exceeded the 5-µg/ml lead limit with an average of 15 µg/ml in duplicate runs. Sample 83 contained the highest lead value of the 113 samples, but this concentration is still a factor of 3 less than the concentration reported in the West German sample (3). Additional supplies of sample 83 could not be obtained from the plant to see if this high lead value was anomalous. The highest zinc level was found in sample 54 with a concentration of 8,660 µg/g, which is a factor of 2 less than the value reported for the West German sample. Although zinc is not a factor in the EP toxicity tests, it is of environmental interest.

TABLE 11. - Maximum concentration of contaminants allowed for EP toxicity test (4 5)

EPA hazardous waste number	Contaminant	Maximum concentration µg/ml
D004.....	Arsenic....	5.0
D005.....	Barium.....	100.0
D006.....	Cadmium....	1.0
D007.....	Chromium...	5.0
D008.....	Lead.....	5.0
D009.....	Mercury....	.2
D010.....	Selenium...	1.0
D011.....	Silver.....	5.0

SUMMARY AND CONCLUSIONS

As part of the Bureau of Mines' minerals environmental technology program, the Avondale Research Center has completed an extensive characterization of dusts generated from U.S. cement kilns. Because of the interest of the EPA and Congress (4-5, 10) in CKD as a large-volume waste of unknown environmental impact, the mineralogical and chemical compositions and the hazardous waste potential of CKD were investigated. Data from mineralogical analysis show that the major constituents of CKD are calcite, lime, and anhydrite with varying amounts of quartz and dolomite.

A total of 28 elements was determined in 113 CKD samples. In addition, seven anion species, carbon dioxide, noncarbonate carbon, and chemically bound water were determined in all samples. Mercury was determined in 16 selected samples.

Chemical analyses show 13 elements or anion species occurring in CKD at concentrations consistently greater than 0.05 wt-pct. These constituents are Al, Ca, Cl^-, CO_2, F^-, Fe, K, Mg, Na, Si, SO_4^{2-}, Sr, and Ti. The upper range limits for heavy metal concentrations such as lead and zinc are a factor of 2 or 3 less than the value reported for a CKD sample from Blaubeuren, West Germany (3).

The U.S. Environmental Protection Agency EP toxicity test was performed on all samples. Only 1 of the 113 samples had a leachate concentration that exceeded any of the limits; it slightly exceeded the criterion for lead.

Cement kiln dust is a large-volume material and a potential resource as a substitute for lime. Any environmental considerations are minor, as the results of this extensive survey show that U.S. CKD is not a hazardous waste as defined by current regulations established under RCRA.

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